Low NO_x Standards, Not-To-Exceed In-Use Testing Program

Public Workshop to Discuss Potential Changes to the Heavy-Duty Engine and Vehicle Emission Standards, Test Procedures, Warranty, and Other Related Heavy-Duty Programs

November 3, 2016

Diamond Bar, California

California Environmental Protection Agency

Air Resources Board

Outline

- Establish Lower NO_X Emission Standard
- Evaluation of the Heavy-Duty In-Use Testing Program
  - Current program
  - Possible modifications to NTE
  - Alternatives to NTE
- Next steps/Workgroup

Establish Lower NO_X Emission Standard

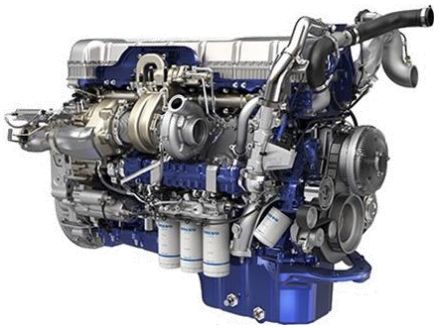
Current Heavy-Duty Engine Standards

- 2010 and newer model year HD engines
  - NOx: 0.20 g/bhp-hr
  - PM: 0.01 g/bhp-hr
- Optional low-NO_X standards
  - Adopted in 2013
  - NOx: 50%, 75%, 90% lower than 2010 standards
  - Two engines certified to the optional standards
    - 8.9 liter natural gas engine - 0.02 g/bhp-hr (90% below standard)
    - 6.7 liter natural gas engine - 0.10 g/bhp-hr (50% below standard)

Establish Low-NO_X Heavy-Duty Engine Standard

- **Goal**:
  - Develop HD low-NO_X engine standard
  - Develop low-load certification cycle
  - Work collaboratively with U.S. EPA to establish national low-NO_X engine standard

- **Timeframe**:
  - ARB Board date: 2019
  - Implementation schedule: 2023 - 2027



R&D on Low NOx Demonstration

- **ARB R&D - Diesel and Natural Gas Engines (Stage 1)**
  - Optimize emissions on the FTP, RMC, Idle, and WHTC
  - Target NO_X emission rate: 0.02 g/bhp-hr (90% reduction) over the FTP
  - Contractor: Southwest Research Institute (SwRI)
  - Cost: $1.6 million

- **ARB R&D – Low Load Optimization (Stage 2)**
  - Optimize system for low load vocational driving
  - Develop new low load certification cycle
  - Evaluate metrics for in-use testing under low load
  - Contractor: SwRI
  - Cost: $1 million

- **Planned ARB R&D**
  - Complement Stage 1 and 2 effort with additional diesel engine
    - Representative of future engine configuration
    - Potential support from partners: U.S. EPA, MECA, air districts, etc.

Evaluation of the In-Use Testing Program

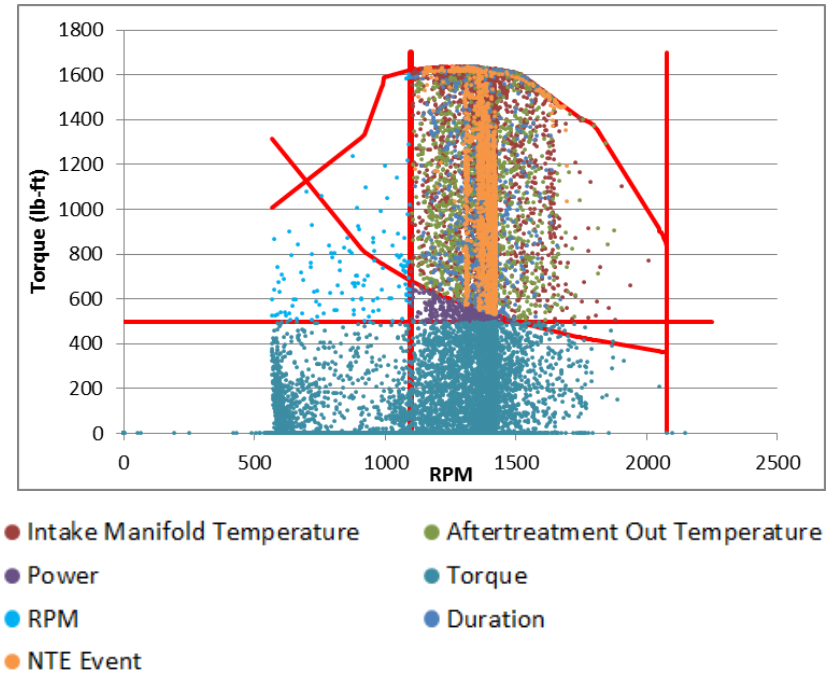
Current Heavy-Duty In-Use Testing Program

- In-use testing ensures that engines meet applicable emission standards throughout their useful life
- HDIUT program adopted in 2005 by U.S. EPA and in 2006 by ARB
- ARB and U.S. EPA jointly select engine families to be tested
- Manufacturers recruit fleets, conduct testing using Portable Emissions Measurement Systems (PEMS)
- Test data and results submitted to ARB and U.S. EPA
- Data is analyzed under the Not-to-Exceed (NTE) requirements

Current Criteria for Valid NTE Events

1. Inside NTE control area
   - > 30% max power
   - > 30% max torque
   - > 15% European Stationary Cycle speed (rpm)
2. Temperature conditions
   - > 250°C (for SCR aftertreatment)
   - Meet minimum intake manifold/engine coolant temperatures
3. At least 30 consecutive seconds meeting above criteria

- Emissions value: work-specific average of 1 Hz data within each NTE event



Most Data Excluded from Emissions Evaluation under Current Program

- Data from 245 tests show
  - Average (mean) data in NTE events included: 5.8%
  - Median: 3.5%
- Potential changes to NTE to reduce data exclusion and increase NO_X evaluated
  - Expand NTE control area
    - Reduce minimum torque
    - Reduce minimum power
  - Lower aftertreatment out temperature minimum
  - Reduce minimum duration of NTE event
  - New guidance on when testing should be conducted

Case Study

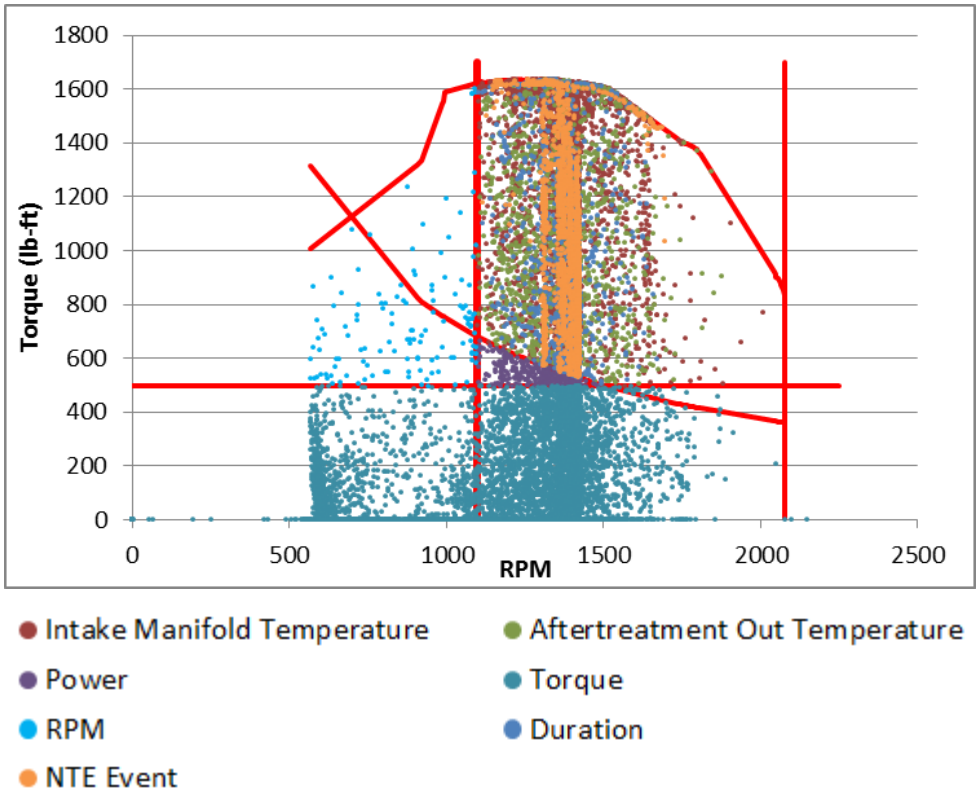
- Demonstrate effects of modifying NTE parameters on amount of data available for emissions evaluation
- Characteristics of test used in case study
  - Vehicle Type: Line Haul
  - Trailer Type: Refrigerated
  - Distance traveled: 260 miles
  - Duration of test: 11.2 hours
  - Non-idle time: 5.6 hours
  - 239 ft net elevation change
  - Region: South

Case Study

- Under Existing NTE Conditions

Parameter	Threshold
Torque	30%
Power	30%
Aftertreatment Temp.	250 °C
Time	30 seconds

Results	
# Events	44
% Time in events	7.1%
without idle	14.6%
% NO_X in events	8.4%
without idle	10.5%
NO_X Pass Ratio	1.00

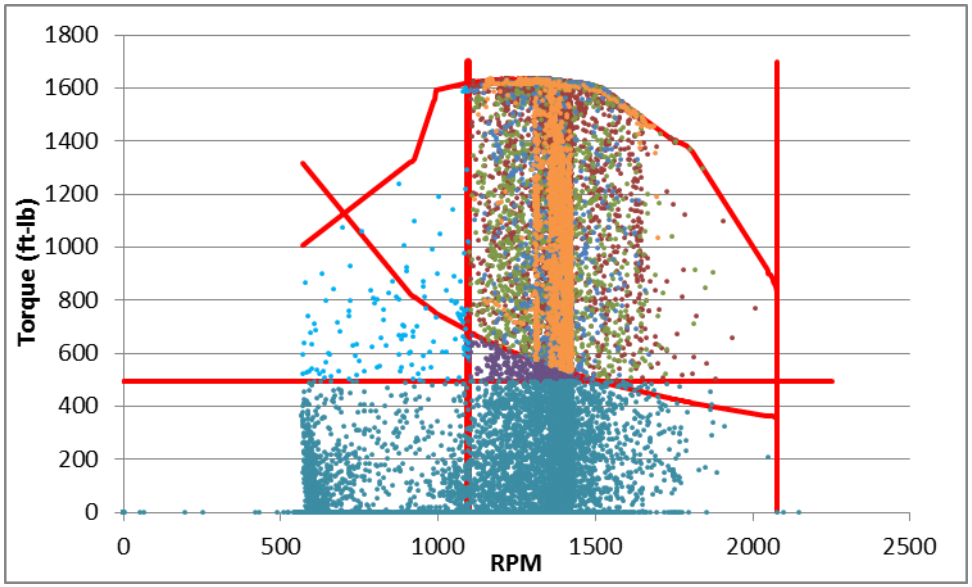


Case Study

- Lower Time Threshold: 20 seconds

Parameter	Threshold
Torque	30%
Power	30%
Aftertreatment Temp.	250 °C
Time	20 seconds

	This case	Base case
# Events	63	44
% Time in events	**8.2%**	**7.1%**
without idle	16.9%	14.6%
% NO_X in events	**9.7%**	**8.4%**
without idle	12.2%	10.5%
NO_x Pass Ratio	1.00	1.00

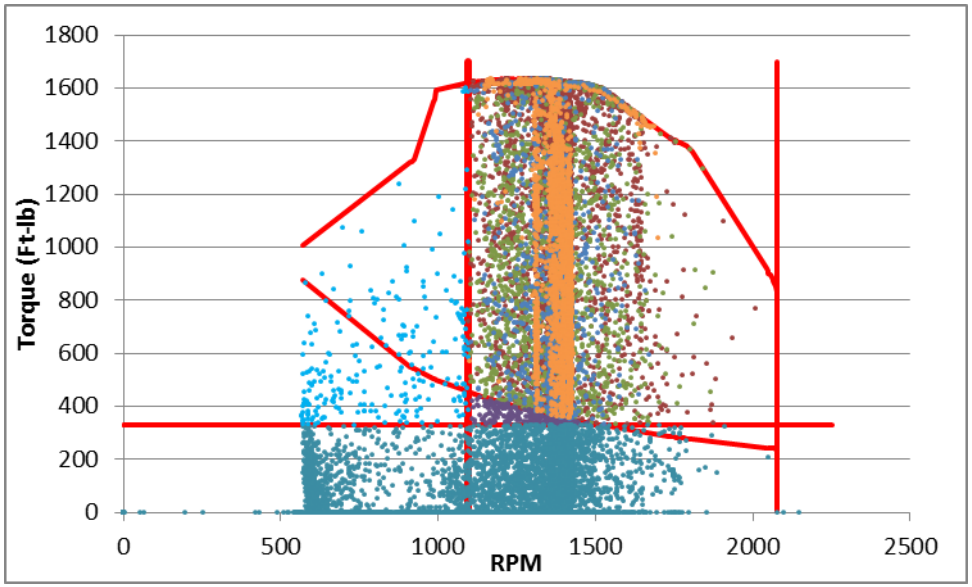


Case Study

- Lower Torque and Power Thresholds

Parameter	Threshold
Torque	20%
Power	20%
Aftertreatment Temp.	250 °C
Time	30 seconds

	This case	Base case
# Events	48	44
% Time in events	**9.2%**	**7.1%**
without idle	19.0%	14.6%
% NO_X in events	**9.8%**	**8.4%**
without idle	12.4%	10.5%
NO_x Pass Ratio	1.00	1.00

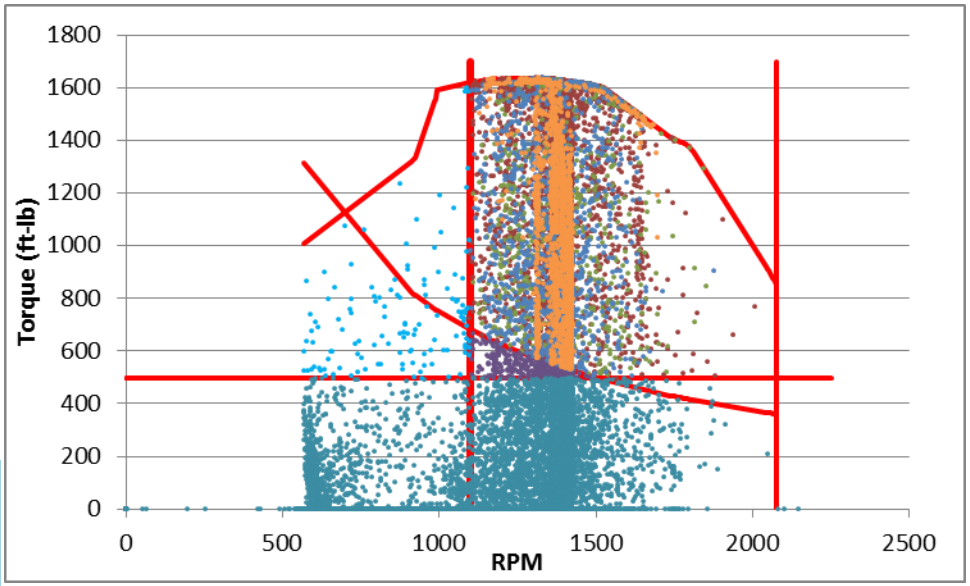


Case Study

- Lower Temperature Threshold: 200 °C

Parameter	Threshold
Torque	30%
Power	30%
Aftertreatment Temp.	200 °C
Time	30 seconds

	This case	Base case
# Events	45	44
% Time in events	7.2%	7.1%
without idle	14.8%	14.6%
% NO_X in events	8.6%	8.4%
without idle	10.8%	10.5%
NO_x Pass Ratio	1.00	1.00

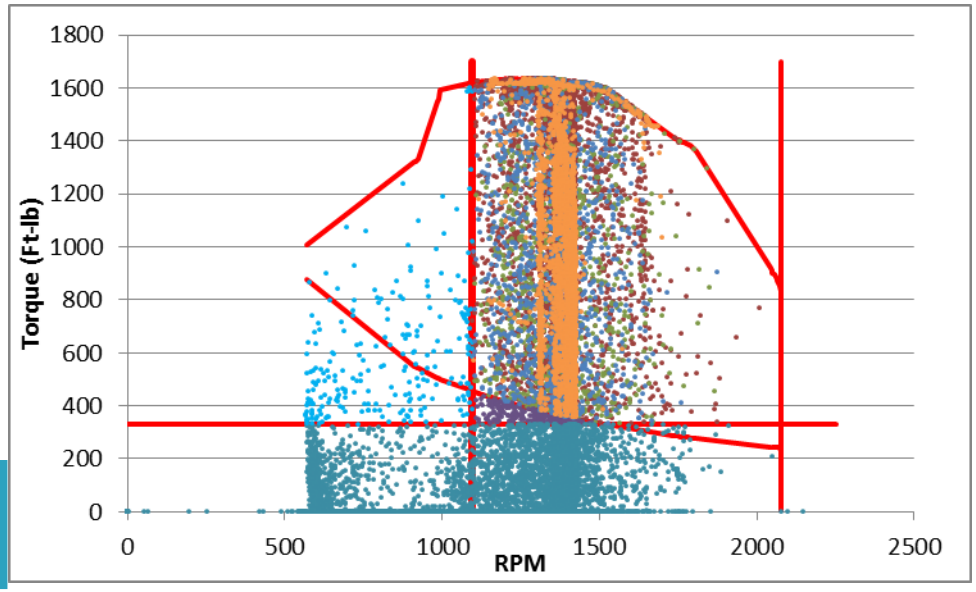


Case Study

- Multiple Parameters

Parameter	Threshold
Torque	20%
Power	20%
Aftertreatment Temp.	200 °C
Time	20 seconds

	This case	Base case
# Events	70	44
% Time in events	10.7%	7.1%
without idle	22.0%	14.6%
% NO_X in events	11.5%	8.4%
without idle	14.5%	10.5%
NO_x Pass Ratio	1.00	1.00

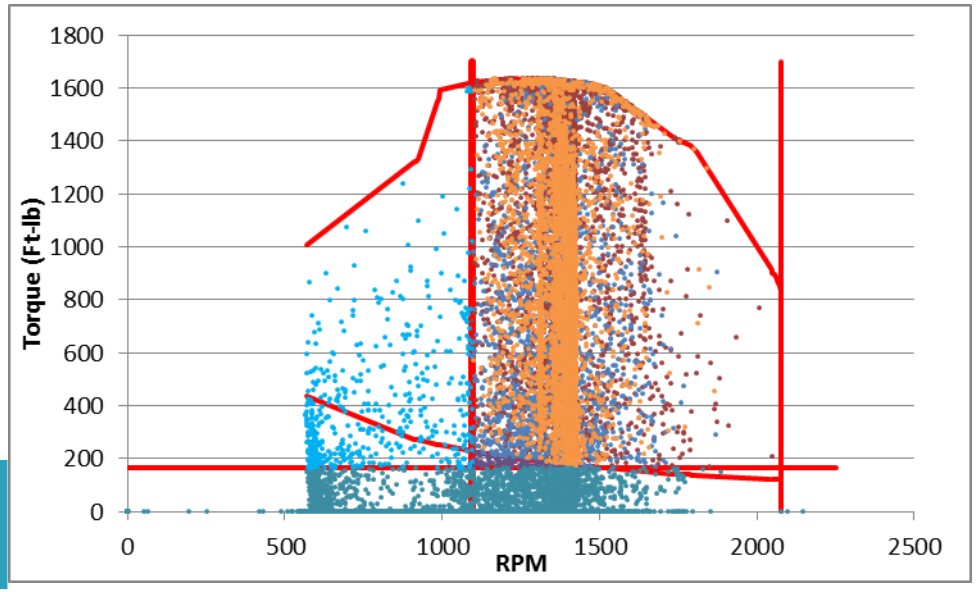


Case Study

- Multiple Parameters

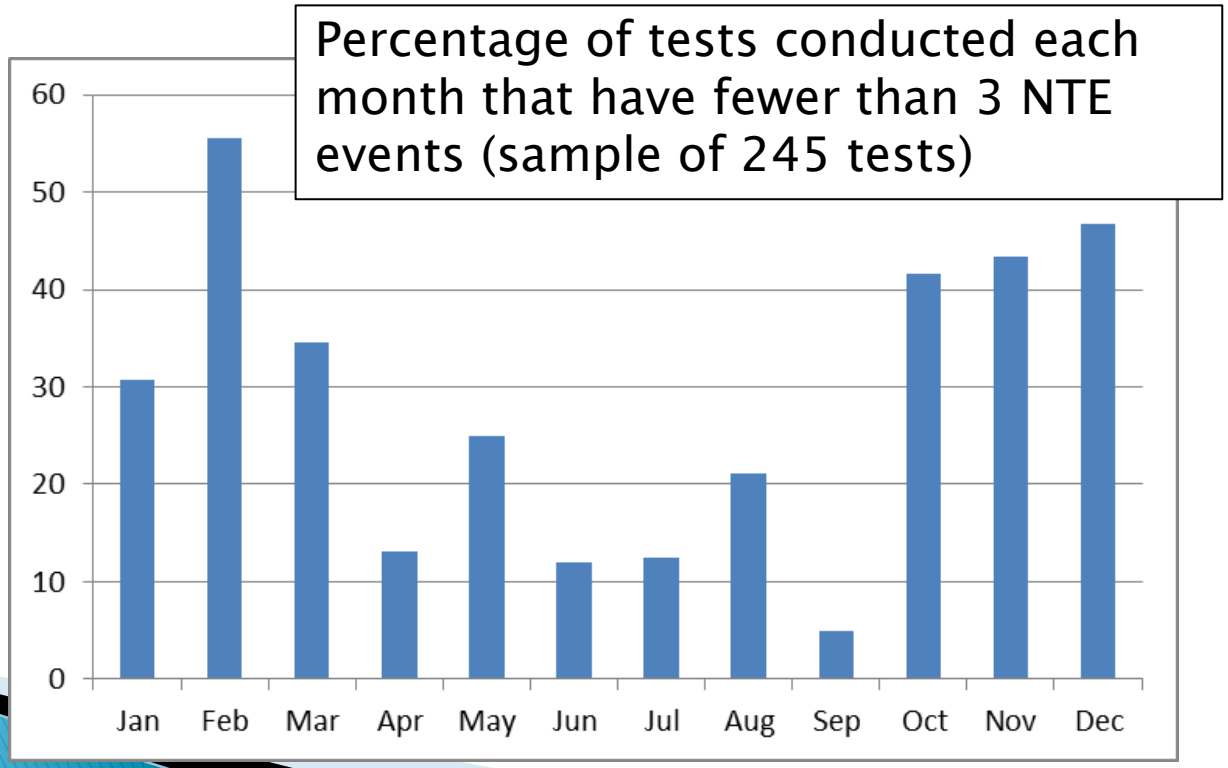
Parameter	Threshold
Torque	10%
Power	10%
Aftertreatment Temp.	No Exclusion
Time	10 seconds

	This case	Base case
# Events	144	44
% Time in events	**15.7%**	**7.1%**
without idle	32.3%	14.6%
% NO_X in events	**22.0%**	**8.4%**
without idle	27.6%	10.5%
NO_x Pass Ratio	0.94	1.00



Test Season Affects Number of Events

- Testing in colder months leads to additional cold temperature NTE exclusions
- Further study on merits of a guidance for time of year and region to test; ambient conditions on day of testing



Impact of Changing Individual Parameters

- The amount of data included in NTE events is increased to 22% under the scenarios presented
- Data is screened out by multiple parameters
  - Point may not be added by relaxing one parameter since another parameter may still exclude the data point
  - Multiple parameters need to be changed to have effect
- Staff will continue analyses of modifications to the NTE parameters and impacts of a guidance on testing conditions

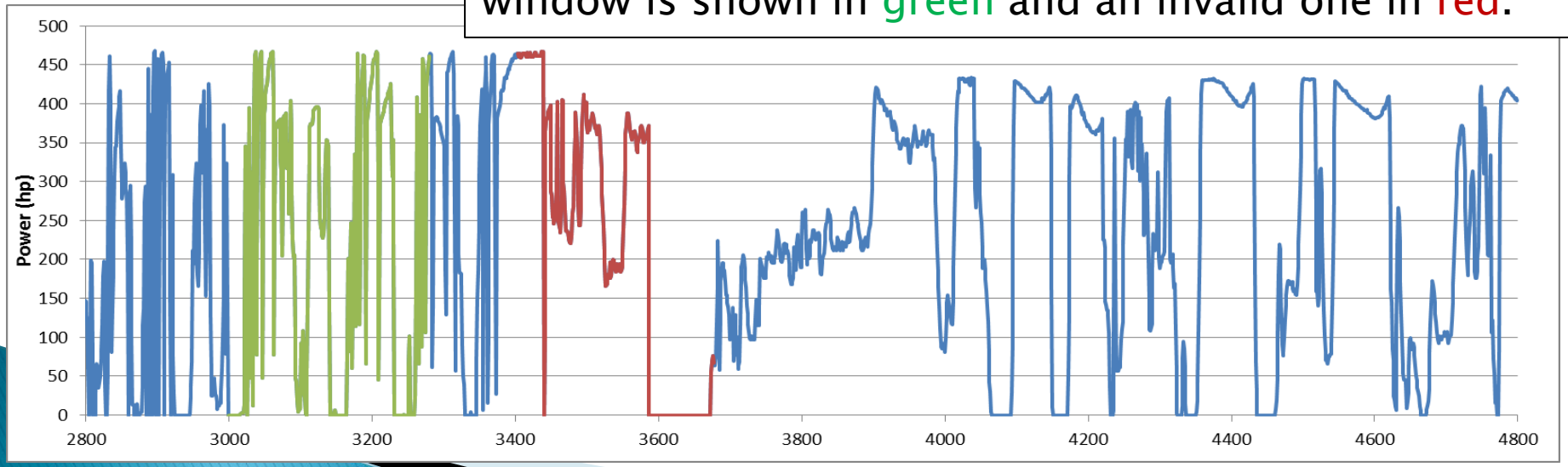
Work-Based Moving Average Window Method

- Adopted in the European Union as part of Euro VI
- Emissions evaluated over segments of data (windows)
  - Work over window equal to work over certification cycle
  - Average power over window meeting percentage of max power
  - Brake-specific emissions: Total emissions emitted in window divided by total work done in window
  - Window emissions ranked and emissions at 90th percentile used to determine compliance
  - Does not have separate temperature-based exclusions

Determining Valid Windows

- Work done each second is added until the cycle work is accumulated (FTP work in this example)
- Average Power = Window work / window duration
- Window is valid if average power > 20% max power

Snippet of data from a test conducted on PEMS: A valid window is shown in green and an invalid one in red.



European Union Program

- Work-based moving averaging windows used in Euro VI's In-Service Conformity program
- Testing done over prescribed route, rather than under revenue service
  - Route consisting of urban, rural, and highway segments
- Minimum 50% of windows must be valid
  - Valid window: average power $\geq$ 20% max power
    - Euro VI undergoing changes to lower limit to 10%
- Compliance threshold of 1.5 times certification standard (no measurement accuracy margin)

Analysis of Work-Based Moving Average Window on Existing Data

- Analyze the same test data as earlier, this time utilizing the work-based window method
  - The engine work done over the FTP was used to define the window work
  - Four average power thresholds used

	30% Power	20% Power	15% Power	10% Power
% Windows Valid	31.9%	40.2%	44.4%	52.2%
90th Percentile Emissions (g/bhp-hr)	0.34	0.58	0.80	0.91
% Time in valid windows	6.1%	8.9%	10.9%	16.2%
% NO_x Emissions in valid windows	9.0%	13.1%	17.0%	**25.8%**

Other Alternatives

- Other alternatives for analyzing PEMS data also exist, including
  - Speed binning (Netherlands Organisation for Applied Scientific Research)
  - Power binning (University of Technology Graz)
- ARB's contract with SwRI will evaluate metrics for in-use testing under low load
  - Grams of NO_X per unit fuel consumed
  - Grams of NO_X per unit CO_2 emitted

Next Steps

- Staff will continue to analyze data under different scenarios
- Projected Board Hearing Date: 2019
  - Additional workshops will be scheduled
- Heavy-duty in-use compliance/testing/NTE workgroup
  - Stakeholders are invited to participate to provide input on staff's ongoing work
  - Additional on-road testing data of heavy-duty vehicles would be greatly appreciated

Rulemaking Schedule

- Board Hearing: 2019
- More workshops will be planned
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